Morphometric analysis of torso arterial anatomy with implications for resuscitative aortic occlusion

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BACKGROUND: Hemorrhage is a leading cause of death in military and civilian trauma. Despite the importance of the aorta as a site of hemorrhage control and resuscitative occlusion, detailed knowledge of its morphometry is lacking. The objective of this study was to characterize aortic morphometry in a trauma population, including quantification of distances as well as and diameters and definition of relevant aortic zones.

METHODS: Center line measures were made (Volume Viewer) from contrast computed tomography (CT) scans of male trauma patients (18–45 years). Aortic zones were defined based on branch arteries. Zone I includes left subclavian to celiac; Zone II includes celiac to caudal renal; Zone III includes caudal renal to aortic bifurcation. Zone lengths were calculated and correlated to a novel external measure of torso extent (symphysis pubis to sternal notch).

RESULTS: Eighty-eight males (mean [SD], 28 [4] years) had CT scans for the study. The median (interquartile range) lengths (mm) of Zones I, II, and III were 210 mm (202–223 mm), 33 mm (28–38 mm), and 97 mm (91–103 mm), respectively. Median aortic diameters at the left subclavian, celiac, and lowest renal arteries were 21 mm (20–23 mm), 18 mm (16–19 mm), and 15 mm (14–16 mm), respectively, and the terminal aortic diameter was 14 mm (13–15 mm). The correlation of determination for descending aortic length (all zones) against torso extend was $r = 0.454$.

CONCLUSION: This study provides a morphometric analysis of the aorta in a male population, demonstrating consistency of length and diameter while defining distinct axial zones. Findings suggest that center line aortic distances correlate with a simple, external measure of torso extent. Morphometric study of the aorta using CT data may facilitate the development and implementation of occlusion techniques to manage noncompressible torso, pelvic, and junctional femoral hemorrhage. (*J Trauma Acute Care Surg*. 2013;75: S169–S172. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Diagnostic study, level III.

KEY WORDS: Torso vascular anatomy; endovascular measurement; CT angiography; noncompressible torso hemorrhage.

In the setting of hemorrhagic shock, maintenance of central aortic pressure is critical to sustain myocardial and cerebral perfusion until resuscitation can be initiated and bleeding can be controlled.[1] Resuscitative aortic occlusion at locations between the origin of the left subclavian artery and the aortic bifurcation can be a life-sustaining procedure, which maintains central pressure and mitigates distal hemorrhage.[2] Currently this maneuver is achieved with an aortic clamp at the time of thoracotomy or laparotomy or with an endovascular balloon introduced through the femoral artery.[3,4]

Despite the potential for resuscitative aortic occlusion to sustain life and control hemorrhage, there is little quantitative information on the morphometry of the aorta or the iliac or femoral arteries. Morphometry, in this context, refers to the diameters at various locations along the aorta and distances between the femoral vessels and major aortic side branches. The current understanding of torso arterial anatomy is mostly based on cadaveric dissection and medical illustration. Even when computed tomography (CT) provides detailed arterial measurements, the imaging is per individual and obtained after injury. For significant advances to occur in the management of hemorrhage, including the use of resuscitative aortic occlusion, a more complete knowledge of aortic and access vessel morphometry is necessary.

The common use of CT following injury has resulted in repositories of imaging data in trauma populations.[5,6] These collections of data include imaging of the aorta, iliac, and femoral arteries stored on systems with software to perform detailed vessel diameter and center line length measurements. Structured collection and analysis of torso arterial measurements from large numbers of CT imaging studies may allow the quantification of morphometric norms. Knowledge of such norms before injury stands to facilitate new techniques in resuscitation and hemorrhage control without the need for fluoroscopy.

The objective of this study was to quantify torso arterial morphometry in a trauma population using a volume of archived CT images. An additional objective was to characterize the correlation of arterial lengths or distances with a novel measure of torso extent.

Submitted: January 30, 2013, Revised: February 20, 2013, Accepted: March 19, 2013.

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DOI: 10.1097/TA.0b013e31829a098d

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **01 AUG 2013**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE
Morphometric analysis of torso arterial anatomy with implications for resuscitative aortic occlusion

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Stannard A., Morrison J. J., Sharon D. J., Eliason J. L., Rasmussen T. E.,

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
United States Army Institute ofSurgical Research, JBSA Fort Sam Houston, TX

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**4**	

PATIENTS AND METHODS

Following institutional review board approval, consecutive trauma patients during a 12-month period, who underwent CT scanning, were retrospectively identified from the Wilford Hall United States Air Force Medical Center database (Lackland Air Force Base, San Antonio, Texas). For inclusion, CT scans were those performed on male patients between the ages of 18 years and 45 years. All CT scans were contrast-enhanced, 64-slice continuous examinations of the chest, abdomen, pelvis, and femoral vessels.

The individual scans were loaded on to a CT workstation running Volume Viewer software (General Electric, Waukesha, WI). Three-dimensional reconstructed angiograms permitted the measurement—in millimeters—of the distance between vessel origins and diameters (Fig. 1*A* and *B*). The aorta was divided into and examined as three previously described zones (Fig. 2).[4] Aortic Zone I extended from the origin of the left subclavian artery to the celiac trunk. Aortic Zone II extended from the celiac trunk to the origin of the lowest renal artery, and the infrarenal aorta (lowest renal to the aortic bifurcation) constituted the aortic Zone III.

The center line length (mm) of each zone was measured, and the luminal diameter of the aorta at the proximal and distal most extent of each of the zones was recorded. In addition, the distance from left and right common femoral artery (CFA) at the midpoint of the femoral head to the aortic bifurcation and the origin of the left subclavian artery was recorded. The CFA landmark was chosen as a plausible site for arterial access. For the purposes of the study, the external measure of torso extent was defined as the straight line distance (mm) from the suprasternal notch of the manubrium to the midpubic symphysis, parallel to the patient's craniocaudal axis.

CT images were examined by a single reader, with 10 scans reassessed de novo and measured at different sessions to assess intrareader variability. Data were collected in an Excel spreadsheet (Microsoft, Redmond, WA) and imported to SPSS version 20 (IBM, New York, NY) for analysis. Distances and diameters were reported as medians, accompanied by interquartile range (IQR) and maximum-minimum values for distribution. Scatter plots were generated plotting aortic zone length against torso extent or height, and a best-fit line was drawn using linear regression analysis. The correlation of determination (R^2) was reported as measures of the strength of the linear regression.

RESULTS

Two hundred male patients underwent CT imaging following traumatic injury between April 1, 2009, and March 31, 2010. There were 112 exclusions (56%) with 102 (51%) removed because of a low-quality contrast bolus or a noncontiguous chest, abdomen, pelvis, and femoral imaging. Eight scans (4%) were excluded owing to inadequate anatomic exposure, and 2 (1%) were excluded owing to abnormal vascular anatomy. The final cohort was composed of 88 patients with a mean (SD) age of 28 (4) years and a median (IQR) torso extent or height of 521 mm (500–536 mm).

Distances or Lengths

The distances (mm) from skin to the left or right CFA was similar, with a median distance of 35 mm and an IQR of 29 mm to 41 mm (Table 1). The distance from the CFA to the aortic bifurcation was longer by 30 mm on the right than on the left side. The median (IQR) distance for the right and left were 197 mm (182–213 mm) and 206 mm (195–219 mm), respectively. The total length of the aorta from the left subclavian to the aortic bifurcation was 340 mm (323–360 mm). Aortic Zone I was the longest, with a median length of 211 mm (202–223 mm). The length of Zone III was 97 mm (91–103 mm), and the length of Zone II was 33 mm (28–38 mm).

Diameters

The diameters of the left and right CFA were the same, measuring 8 mm (7–9 mm) (Table 2). Aortic diameter was the smallest (14 mm [13–15 mm]) at the bifurcation. Aortic diameter increased to 15 mm (14–16 mm) at the lowest renal artery, 18 mm (16–19 mm) at the celiac trunk, and 21 mm (20–23 mm) at the level of the left subclavian artery (Table 2).

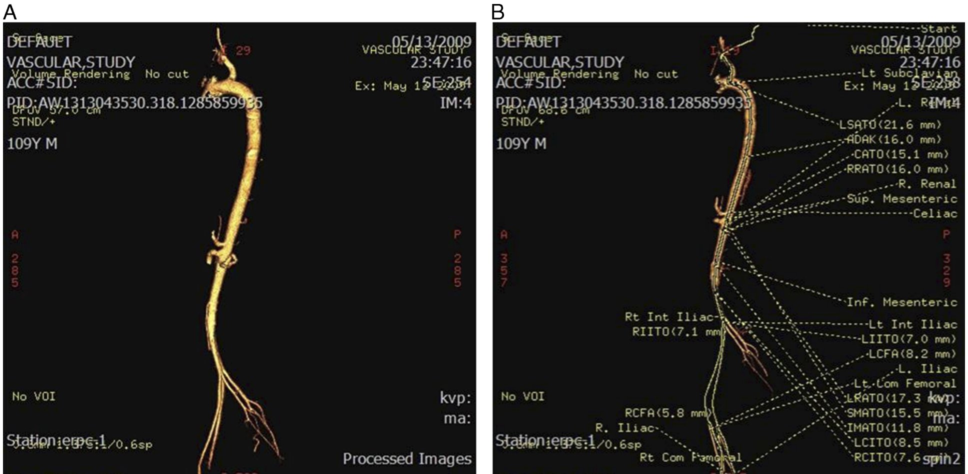

Figure 1. *A*, CT three-dimensional rendering of the aorta, iliac, and femoral arteries. *B*, The same image in *A*, with superimposed center line measurements.

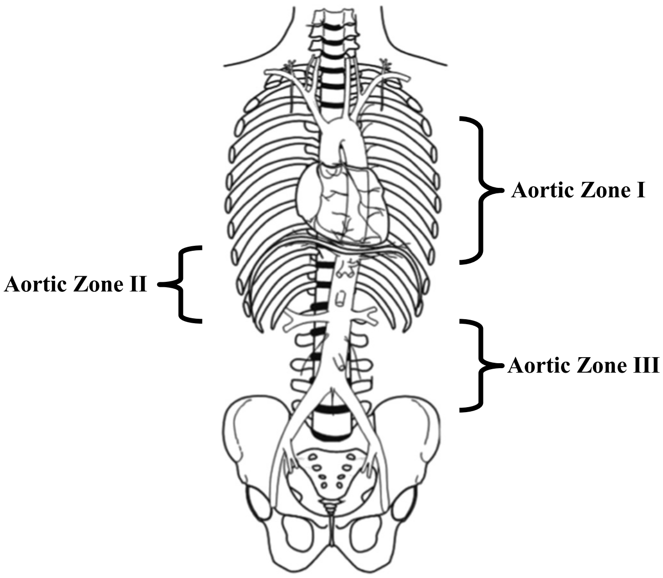

Figure 2. Line drawing demonstrating the three aortic zones.

Linear Regression

Length measurements of the descending aorta were plotted against the measurements of torso extent or height (Fig. 3), and linear regression was used to apply a best-fit line. An R^2 of 0.454 demonstrated that torso extent alone was able to explain more than 45% of the variability in aortic length. This method was repeated for the individual aortic zones (Fig. 4) with both aortic Zones I and III resulting in an R^2 of 0.294 and 0.212, respectively, indicating that other explanatory variables may be involved. Zone II had a low R^2 of 0.065, suggestive of a poor linear relationship to torso height.

DISCUSSION

This study is the first to report numerical characterization of the aorta, iliac, and femoral arteries using stored CT images of male trauma patients. In addition, this analysis reports the morphometric measures of three clinically relevant aortic zones and demonstrates a correlation between aortic length and torso height. This capability has largely come about owing to scanning techniques and software originally designed for the planning of endovascular intervention, but the commonality of CT imaging in trauma extends the applicability.[5,6]

This study compliments our group's previous work in torso trauma, where the aorta has been characterized into three zones.[4] Zone I extends from the origin of the left subclavian artery to the celiac trunk and has a median length of 211 mm. Zone II is from the origin of the celiac trunk to the lowest renal artery and has the smallest median length of 33 mm. The infrarenal aorta is Zone III and is 97 mm in median length. Aortic Zones I and III were described as regions of occlusion, to achieve inflow control and afterload support of patients in extremis with non-compressible torso hemorrhage.[4]

TABLE 1. Measurements of Key Vascular Distances

Distance, mm	Minimum	25th Percentile	Median	75th Percentile	Maximum
Aortic Zone I	96	202	211	223	260
Aortic Zone II	16	28	33	38	129
Aortic Zone III	66	91	97	103	123
Left CFA to AB	146	182	197	213	241
Right CFA to AB	163	195	206	219	244
Skin to Left CFA	10	29	35	41	76
Skin to Right CFA	11	29	35	40	78

Aortic Zone I extended from the left subclavian to celiac trunk; aortic Zone II extended from the celiac trunk to lowest renal artery; and aortic Zone III extended from the lowest renal artery to AB.
AB, aortic bifurcation.

TABLE 2. Vessel Diameters at Key Vascular Landmarks

Diameter, mm	Minimum	25th Percentile	Median	75th Percentile	Maximum
Aorta at Left SCA	16	20	21	23	27
Aorta at celiac trunk	12	16	18	19	23
Aorta at LRA	11	14	15	16	19
Aortic Bifurcation	10	13	14	15	18
Left CFA	5	7	8	9	11
Right CFA	4	7	8	9	12

LRA, lowest renal artery; SCA, subclavian artery.

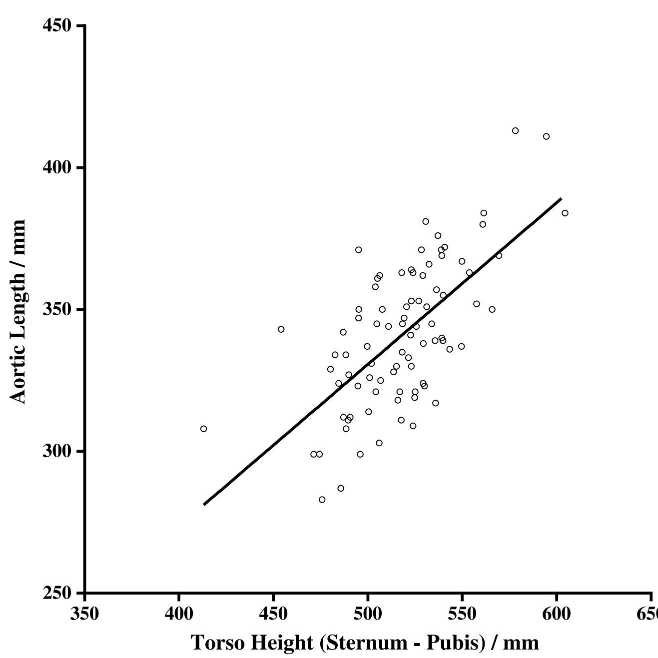

Figure 3. Scatter plot of torso height against descending aortic length with accompany best-fit line.

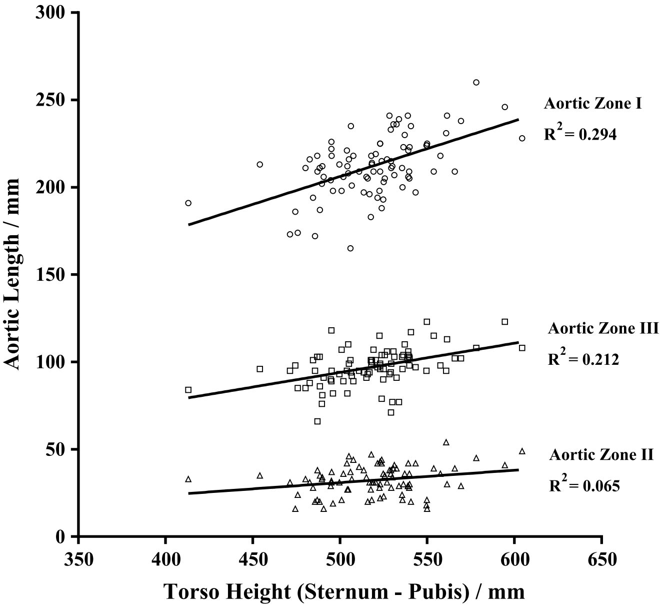

Figure 4. Scatter plots of torso height against the length (mm) of the three aortic zones with accompany best fit lines.

Zone I is the suggested region of occlusion for patients with abdominal exsanguination and/or circulatory collapse/arrest. Zone III occlusion provides terminal aortic control for patients with exsanguinating pelvic and/or inguinofemoral junctional hemorrhage. Zone II or the paravisceral segment is a zone of no occlusion and is conveniently the shortest zone.

Aortic occlusion can be achieved by a number of methods—open and endovascular. Open aortic cross clamping following resuscitative thoracotomy is well described in both military[7] and civilian[8] settings. However, this is only generally possible in appropriately resourced facilities and is often performed as a reactive maneuver following the loss of a central pulse and is associated with poor outcome.[3,7]

Resuscitative endovascular balloon occlusion of the aorta is a minimally invasive, proactive technique designed to be used in patients with hemorrhagic shock, which can support the circulation until definitive hemorrhage control.[4] Critical to this adjunct is correct balloon placement, of which radiographic imaging may not always be possible. Morphometric analyses, such as the one presented in the current study, will help guide the deployment of such devices.

This study has a number of important limitations relating to design, population, and technical issues. This study is retrospective in nature, which may mean that not all eligible patients were identified; although by using a computerized radiology database, rather than case records, this should be minimal. The current study also only examined a male population, which limits the reported findings to men, because women do have morphologic differences. Male sex was chosen because there were insufficient female subjects available for an adequately powered analysis. The analysis of this relatively homogeneous population has the effect of producing a narrow IQR of values. However, the study population is reflective of most trauma populations, which are dominated by young men.

The biggest limitation is that 56% of the originally identified cohort were excluded—the majority (91%) due to poor contrast quality. It is unclear whether this introduces a bias to the distribution of measurements. It may be the case that a larger sample size, with fewer exclusions, will improve the strength of the linear regression.

CONCLUSION

The current study is the first numerical characterization of aortic zones, demonstrating correlation to torso height, using a CT data repository. First, this demonstrates both the feasibility and limitations of this methodology, which may be applicable to other morphometric analyses. Second, these results permit the application of numeric planning to future resuscitative zinterventions for non-compressible torso hemorrhage. This is particularly relevant to the emerging use of endovascular technology, which is an exciting new development in torso hemorrhage control. Further study in a broader population that includes female torso anatomy is warranted to develop the application of morphometric analysis in torso trauma.

AUTHORSHIP

A.S. contributed to the study concept, data acquisition, and writing. J.J.M. contributed to the data analysis, interpretation, and writing. D.J.S. contributed to the data analysis, interpretation, and writing. J.L.E. contributed to the study concept, data interpretation, and writing. T.E.R. contributed to the study concept, data interpretation, and writing.

ACKNOWLEDGMENT

We are very grateful to Mr. Peter Williams and Thomas Seay, MD, of the Wilford Hall Radiology Department who assisted with the acquisition of the data used in this study.

DISCLOSURE

The authors declare no conflicts of interest.

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